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# Demonstration Of Biodegradable, Environmentally Safe, Non-Toxic Fire Suppression Liquids

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**Daniel Madrzykowski  
David W. Stroup, Editors**

**July 1998**



**U.S. Department of Commerce  
Technology Administration  
National Institute of Standards and Technology  
Gaithersburg, MD 20899**



*Prepared for:*  
**Federal Emergency Management Agency  
U.S. Fire Administration  
Emmitsburg, MD 21727-8998**

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**U.S. Department of Commerce**  
**William M. Daley, Secretary**  
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**Gary R. Bachula, Under Secretary for Technology**  
**National Institute of Standards and Technology**  
**Raymond G. Kammer, Director**



*Prepared for:*  
**Federal Emergency Management Agency**  
**James Lee Witt, Director**  
**U.S. Fire Administration**  
**Carrye B. Brown, Administrator**



# **CHAPTER 1**

## **INTRODUCTION**

**Daniel Madrzykowski**  
**National Institute of Standards and Technology**  
**Building and Fire Research Laboratory**  
**Fire Safety Engineering Division**  
**Large Fire Research**  
**Gaithersburg, Maryland**

# INTRODUCTION

The Building and Fire Research Laboratory (BFRL) of the National Institute of Standards and Technology (NIST), under the sponsorship of the United States Fire Administration (USFA), has conducted a series of experiments to demonstrate the suppression effectiveness of water-based fire fighting agents. Accepted test procedures for suppression effectiveness do not currently exist. Therefore, the results of these experiments are a first step toward establishing standardized tests for evaluating the fire fighting effectiveness of water-based agents. Because issues of toxicity and environmental effects of commonly used agents are of paramount concern to the fire fighting community, this report includes as an appendix, Wildland Fire Foam Characterization. This characterization study includes methods for demonstrating environmental safety and toxicity as developed by the United States Department of Agriculture (USDA).

The work reported here addresses a broad range of tests in order to determine those parameters that most critically effect fire-fighting performance.

This project was a result of Public Law 103-327 [1,2]\* which provided funding to the USFA, to demonstrate biodegradable, environmentally safe, nontoxic fire suppression liquids which are effective on Class A, B and many D fires. Since no standardized test methods or protocols were available to demonstrate the effectiveness of water-based fire suppression liquids, USFA tasked BFRL with developing a methodology for conducting a demonstration. This task is consistent with NIST's mission to advance measurement science and develop standard test methods and with BFRL's program to improve fire safety.

## 1.1 Background

Water is the most widely used fire extinguishing agent because it is effective, environmentally friendly, nontoxic, inexpensive and in many cases, readily available. In addition, water has a very high heat of vaporization per unit mass, at least four times as high as that of any other nonflammable liquid [3]. However, water is not an ideal fire extinguishing agent for many materials such as liquid hydrocarbon spill fires and metal fires.

The latent heat of vaporization of water is 2254.8 kJ/kg (970.3 Btu/lb.) [4]. This means that 2254.8 kJ (2138.7 Btu) of energy is required to change 1 kg (2.2 lb.) of water into steam. When water is vaporized, its volume increases approximately 1,600 times. Because the energy absorbing capabilities of water are well quantified, they can be used as a basis to calculate the theoretical minimum delivery rate of water needed to extinguish a burning material with a known heat (energy) release rate. Unfortunately, experience has shown that water must be applied at 10 to 100 times the theoretical rate in practice to control and extinguish the fire [5]. As a result of this apparent inefficiency and the need to address fires containing a wide variety of materials, water-based fire fighting additives have been utilized for many years to enhance the fire fighting capabilities of

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\* Numbers in brackets refer to the literature references at the end of each chapter.

ordinary water. As mentioned above, no quantifiable method to gauge the effective of these agents currently exists.

The most widely used of the water-based agents are the foams used on Class B (liquid hydrocarbon) fires. Agents designed primarily for Class A (ordinary combustible) fires have been used most extensively in conjunction with wildland fires. More recently these agents have been promoted for use on a wider range of Class A and in some cases Class B and D (combustible metal) fires. These agents are frequently claimed to be more effective than plain water while being environmentally safe. In some cases, they are also claimed to reduce the quantity and toxicity of smoke. To gain an understanding of how additives might enhance the fire suppression capabilities of water, it is important to examine the principles of fire suppression.

### **1.1.1 Overview of Fire Suppression**

While there are many texts which provide detailed descriptions of the mechanisms of fire suppression [3,4,5,6] only a basic overview is provided here. A fire is a chemical reaction in which oxygen combines with a fuel and produces heat and light. The energy from the fire is transferred to the surroundings by two heat transfer mechanisms, convection and radiation. The transfer of heat by a medium, such as gas or liquid, is convection. The transfer of heat via electromagnetic waves, such as light, is radiation.

While a fuel source could be a solid, a liquid or a gas, only the gas can be directly involved in the fire. In the case of solid or liquid fuels, the temperature of the material must be high enough for it to gasify and then react with the oxygen in the air to burn. NFPA 10, Standard on Portable Fire Extinguishers [7], classifies fires based on fuel type. A Class A fire involves ordinary combustibles such as wood, textiles, rubber and plastics. A Class B fire involves liquid hydrocarbons, such as gasoline or oil. Class C fires may involve ordinary combustibles and /or liquid hydrocarbons, in conjunction with energized electrical equipment. The last category, Class D fires, involves combustible metals such as magnesium, titanium or zirconium.

There are four means to extinguish a fire: remove the fuel, remove the oxygen, cool the fuel, or chemically interfere with the reaction. It is important to understand that fires and the optimum means of suppressing them can depend on the fuel or the fuel geometry. If the fire is located in an open area, where there is no impediment to oxygen reaching the combustion zone of the fire, the fire is fuel limited (Figure 1). If the fire is located in a closed compartment, where the amount of oxygen available for combustion is limited, the fire is considered ventilation limited (Figure 2). The rate of heat release that can be supported by a given ventilation opening can be readily calculated [8].

Given water's excellent heat absorption characteristics, its primary means of suppressing a fire is by cooling the fuel. In order for the water to cool the fuel, it must make contact with the fuel surface. Water works well on many Class A fires. However, some fuels, such as rubber, naturally repel water. Since it is difficult for the water to remain on hot rubber, the ability to transfer the heat from the rubber is limited. The suppression effects of the water could be enhanced if the water were held in place on the hot fuel.

Other Class A fires are deep-seated, meaning the surface area involved in combustion is larger than the exterior surface area of the burning item and the pyrolyzing surfaces are shielded from direct water application. If the water could penetrate to the pyrolyzing surfaces it would cool them. Due to the relatively high surface tension of water, it typically beads up and rolls off of the fuel surface and does not penetrate it.

Water has a number of secondary suppression effects, such as cooling the combustion zone, reducing radiation feedback to the fuel surface and steam generation, which can displace the oxygen. Steam generation works especially well in ventilation limited situations.

### **1.1.2 Water-Based Fire Suppression Agents**

The use of additives to enhance the performance of water is not new. Mechanical foams made from water additives were in use as early as 1904 [9]. Since that time, foam agents such as aqueous film forming foam, AFFF, developed by the U.S Naval Research Laboratory in the early 1960's, have gained widespread acceptance for use on many, Class B fires. There are a number of commercially available water-based fire suppression agents designed primarily for Class A fires. Generically, these agents can be classified as surfactants which reduce the surface tension of water, potentially modifying its fire fighting capabilities.

There are a number of standards [10-15] for assessing water-based fire suppression agents. However, most of the criteria do not address the fire fighting (protection/suppression) capabilities of the agent. This is particularly true for Class A and Class D fires. An evaluation protocol is needed to measure the fire fighting capability or effectiveness of these agents. By developing demonstration methods for relating the performance of each agent to plain water, the effectiveness of the agents in given situations could be evaluated. This would enable the fire protection community to select the most cost effective fire suppression agent(s) to fit their specific needs.

### **1.1.3 Agents Selected for Demonstration**

Given the time constraints and the developmental nature of this program, only a limited number of agents could be used. These agents were chosen from a list of water-based fire suppression agents currently meeting the interim requirements of U.S. Forest Service Specification 5100 [16]. The agents on the 1995 qualified products list (QPL) are: Angus ForExpan S, Ansul Silv-Ex, Chemonics Fire-trol FireFoam 103 and 104, Monsanto Phos-Chek WD 881, Pyrocap B-136 and TCI Fire Quench\*. All of these agents are recognized as meeting the U.S. Forest Service Specification 5100 Interim Requirements for environmental impact, human health safety, and physical properties.

Utilizing agents from the QPL provided products with an existing database of information that could not otherwise have been obtained within the time and funding constraints of this project. Four

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\* Certain equipment or materials are identified in this report. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology or the U.S. Fire Administration, nor does it imply that the equipment or materials identified are necessarily the best available for the purpose.

agents, representative of a cross section of the agents on the QPL, were chosen based on differences in selected physical properties data and cost. The specific product names used for the fire protection/suppression demonstration will not be identified in this report.

The impact of the physical properties or characteristics of the water-based fire fighting agents on their effectiveness was examined through laboratory and large-scale fire suppression tests. The physical characteristic tests were used to determine which properties or characteristics, if any, of the agent are indicators of enhanced fire fighting capabilities. Examples of the parameters which were considered are surface tension, expansion ratio, thermal conductivity, and concentration ratio.

For products on the QPL, field use information was available in addition to the environmental impact, human health safety and physical properties. Water-based agents intended primarily for Class A fires are used on a regular basis by a limited number of fire departments around the country. A number of these departments were contacted to provide input on their experience using these water-based agents. The experience gained by these departments is useful in determining the situations in which water-based agents are most effective. This type of information was invaluable in developing the protocol for a demonstration of fire fighting effectiveness.

## **1.2 Objective and Tasks**

The objective of this project was to develop methods for demonstrating biodegradable, environmentally safe, nontoxic fire suppression liquids which are effective on Class A, B and many D fires. The demonstration project was divided into four specific tasks:

1. Conduct a workshop with users, manufacturers and researchers interested in biodegradable, environmentally safe, nontoxic fire suppression liquids.
2. Collect information on fire suppression agents which are considered by their manufacturer to be biodegradable, environmentally safe, nontoxic fire suppression liquids which are effective on Class A, B and many D fires.
3. Develop methods as required and assess the biodegradability, environmental safety, toxicity and physical properties of a limited number of water-based fire fighting agents.
4. Develop methods as required and demonstrate the fire fighting effectiveness of a limited number of water-based fire fighting agents for Class A, B, and many D fires.

### **1.2.1 Workshop Summary**

A workshop was held in Gaithersburg, MD on June 27, 1995. The workshop had three objectives:

1. to brief the attendees on the objectives, scope and approach of the demonstration project,
2. to solicit comments and suggestions on the demonstration project and obtain any available information on previous fire suppression effectiveness test results, and
3. collect field use experience from the fire service on water-based fire suppression agents.

The meeting was attended by fire fighting agent manufacturers, fire fighters, researchers and special experts in the field of fire fighting with water-based fire fighting agents. A list of invites/attendees can be found in Appendix A. The agent manufacturer's group was composed of representatives from Angus, Ansul, Chemonics, Monsanto, and Pyrocap. Each manufacturer has an agent on the U.S. Forest Service's Qualified Products List for Wildland Fire Chemicals. Each of the agents on the list has met the U.S. Forest Service Specification 5100 Interim Requirements for environmental impact, human health safety and physical properties.

Representatives from five geographically and service area diverse fire departments which use Class A agents attended as end users. The fire departments represented were: Fairfax County, VA; Harrisburg, PA; Los Angeles County, CA; Nashville, TN; and Travis County, TX.

The research group was composed of scientists and engineers from: Bureau of Land Management; Hughes Associates; U.S. Forest Service's Intermountain Fire Science Laboratory; Underwriters Laboratories; and NIST. Each member in this group has significant experience in developing and/or conducting tests with liquid fire fighting agents.

The special experts were individuals who had published papers on liquid fire suppression agents and their use by the fire service or had been involved in a liquid fire suppression agent research program as a participant or a sponsor.

Presentations were made on the proposed demonstration plan, the current status of the Forest Services' efforts to characterize the physical characteristics of wildland fire foam (Class A foam), the results of the National Fire Protection Research Foundation's fire suppression effectiveness studies and an end users perspective on the use of Class A foam by an urban fire department. After the presentations, the groups met separately to develop comments and recommendations on the proposed demonstration plan. Each group discussed the issues of concern or the issues of priority that they felt needed to be addressed by the project and developed prioritized lists of recommendations. The groups were reconvened and each group made a presentation to the collective attendees. All of the presentations then were discussed by the groups, and the results of the meeting were summarized.

The major recommendations were:

1. Class A fire fighting effectiveness should be the focus of the project.
2. Utilize existing standardized tests to demonstrate the fire fighting effectiveness on Class B and D fires.
3. Test scenarios should include fire knockdown, "overhaul", and exposure protection.
4. Testing should be conducted at "real-life scale" with 100 gpm flow rates when possible.

5. Efforts characterizing the physical, environmental safety and toxicity attributes of liquid fire fighting agents should continue.

These recommendations were incorporated into this research project.

### **1.2.2 Survey of Water-based Fire Suppression Agents**

As part of this project, a list of names and addresses of manufacturers of Alternative Liquid Fire Extinguishing Agents that are marketed in the U.S. as being suitable for Class A fires, Class A and B fires and Class A, B and D fires was compiled and is included in this report as Appendix B. Information was found on twenty-nine commercially available agents. The list includes agents which are described as wetting agents, emulsifiers, foams, and gels. According to the agent manufacturers, all of these agents are environmentally safe or biodegradable. Of the twenty-nine agents, all are advertised as effective on Class A fuels, twelve of the agents are also advertised as effective on Class B. Three of the agents are advertised as effective on Class A, B and D fuels. The results of the survey are summarized in Table 1.

While this list of agents is by no means a complete listing of liquid fire fighting agents, it does demonstrate that there is a wide range of fire suppression liquids commercially available. The list also indicates the need for a standard method for evaluating the performance of these fire-fighting agents so that manufacturers and their customers in the fire service can have more information for decisions.

The environmental and health safety assessment methods called for in Task 3 are addressed in Appendix C. The following chapters of this report address the results of Task 4 outlined above. Finally, the results for this project are summarized and recommendations are made for the evaluation of water-based fire suppression agents.

### **1.3 References**

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14. NFPA 298, Standard on Foam Chemicals for Wildland Fire Control, 1989 ed., National Fire Protection Association, Quincy, MA.
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16. Qualified/Approved Wildland Fire Chemicals, USDA, Forest Service, Washington Office, 1/18/95.

**Table 1. Sample of commercially available liquid fire fighting agents, their fire suppression capabilities according to fire class and environmental safety as listed in the manufacturer's literature.**

Agent	Class A Fires	Class B Fires	Class D Fires	Comments
Angus Forexpan 'S'	X			"outstanding environmental characteristics"
Ansul Silv-Ex	X			"safeguarding environment"
Baum's Pyrocool	X		X	"biodegradable"
Chemguard Class A Plus	X			"environmentally friendly, biodegradable"
Chemonix Fire-Trol Class A Firefoam	X			
Blackout Class A Foam	X			"biodegradable"
Drench	X	X		"biodegradable, non-toxic"
Control A	X			"biodegradable, safe for environment"
ECO-Foam 2004	X	X		"environmentally friendly"
FireXPlus	X	X		"enhances bioremediation"
Gem Enviro-skin	X	X		"assuming Class B since agent is described as "film-forming foam" "not to be used on Class C and D fires"
Fine Water DP30	X			"biodegradable"
Fine Water HS	X			"biodegradable"
Coldfire	X	X	X	"biodegradable, non-toxic"
Barricade	X			"safe, non-toxic"
Fuel Buster	X	X		"environmentally safe"
Wetting Agent Class A Concentrate	X			
Monsanto Phos-Chek	X			"biodegradable"
Defense Class A Foam Concentrate	X			"non hazardous, biodegradable"
Water Stretcher Class A Foam	X			"biodegradable, no environmental hazard"
Nochar's E112	X			"water soluble, non hazardous"
FireBlok	X	X		"biodegradable"
Pyrocap B-136	X	X	X	"environmentally safe"
Pentro-Wet	X	X		"biodegradable"

Agent	Class A Fires	Class B Fires	Class D Fires	Comments
Fire Quencher				
Water Plus	X			"biodegradable"
BioSolve PinkWater	X	X		"biodegradable"
Wetter Water Water Extender	X			"biodegradable, non toxic, environmentally safe"
U.S. Class A Foam	X			"biodegradable"
AFFF ATC Fire Out 1 Fire Fighting Foam	X	X		"biodegradable"

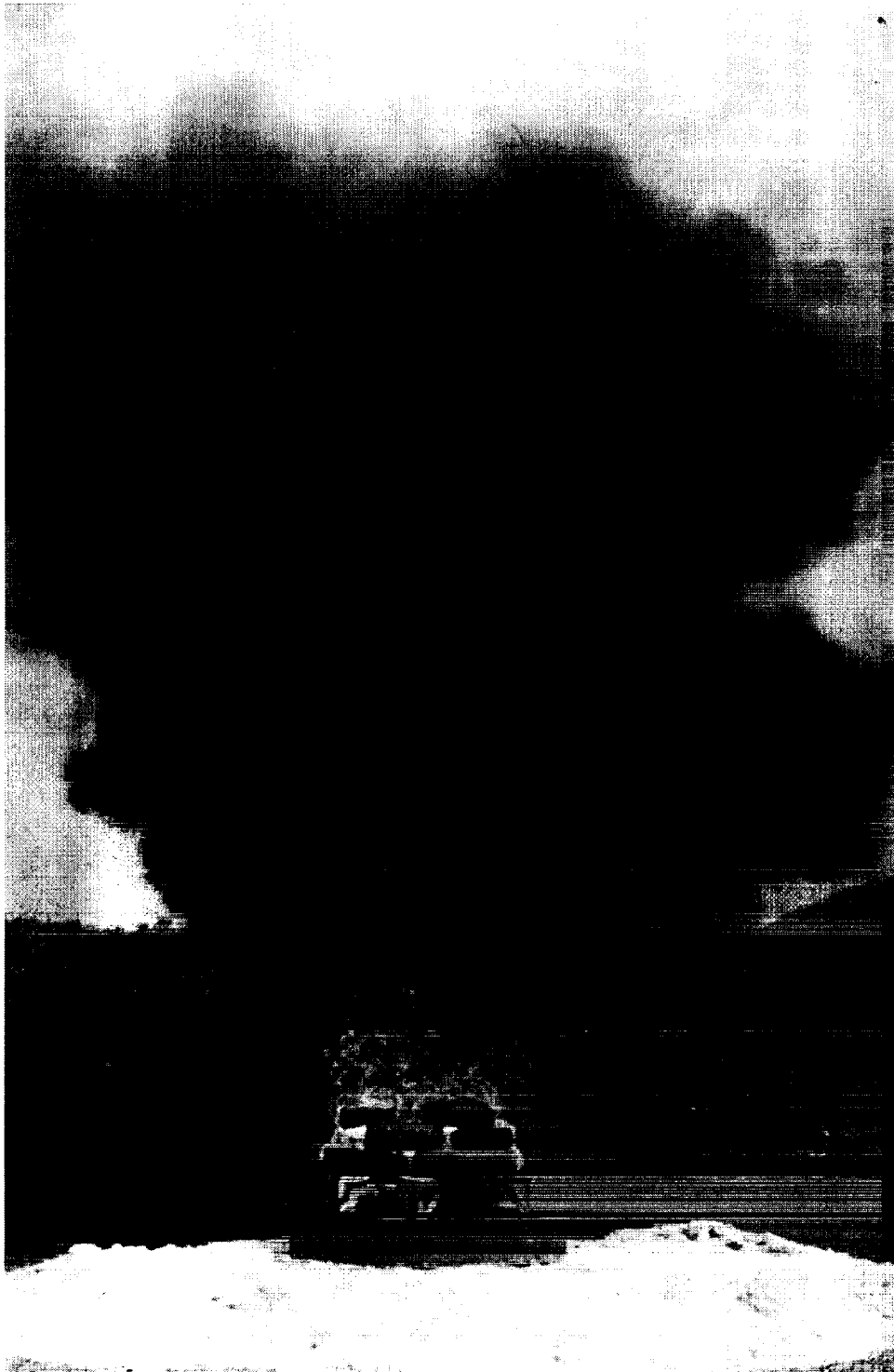


Figure 1. Fuel Limited Fire

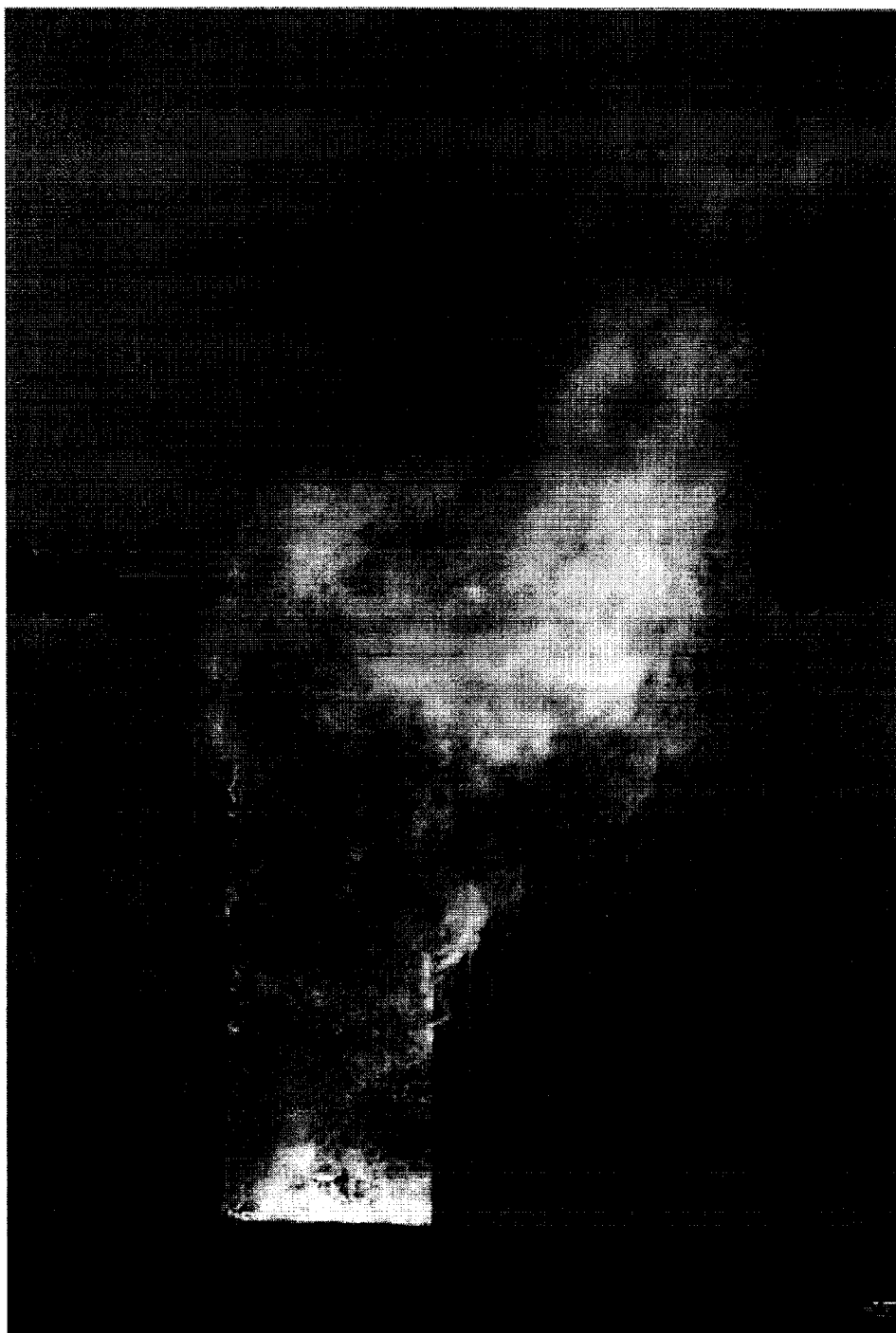


Figure 2. Ventilation Limited Fire